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THE IMPACT OF CANADIAN FUEL PROPERTIES ON EXHAUST EMISSIONS FROM HEAVY DUTY TRUCK AND BUS ENGINES

TE 86-13

DISCLAIMER

This study was carried out with the cooperation of the Department of Energy, Mines and Resources. However, the views expressed in the report are those of the author and do not necessarily reflect the views of the Department.

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EXECUTIVE SUMMARY

The Canadian government is evaluating social and economic impact of emissions standards for heavy duty diesel engines. The tests in this report were jointly sponsored by Energy Mines and Resources (EM&R) in Canada and Cummins Engine Company. Their objective was to determine the performance and emissions contribution of two typical 1990 Canadian diesel fuel compositions in heavy duty diesel engines with respect to the U.S. EPA emissions standards for 1988, 1991 and 1994.

Transient cycle emissions tests were carried out on two heavy duty engines (Cummins NTCC-400 and L10-270) with three fuels. Two of the experimental fuels supplied by Canadian refining industry included a blend from entirely synthetic crude (Tar Sands). Emissions from these fuels are characterized against fuel used by Cummins for EPA certification. The range of fuel properties included: Cetane No. 37-42; Aromatics 27-58%; Fuel Sulphur <0.01 - 0.4% in weight. In the transient test cell environment, the engine performance is not affected by the fuels tested.

The EPA heavy duty diesel engine emissions standards call for an increased severity of emissions limits [especially particulate emission (PART) limits] as summarized below.

Emissions gm/bhp-hr	Present	Future EPA Limits		
	1986	1988	1991	1994
HC	1.3	1.3	1.3	1.3
NO_x	10.7	6.0	5.0	5.0
PART	-	0.6	0.25	0.10

The increased severity of the emissions standards necessitates a change in engine design specifications. A lower design target than these emissions limits is needed to meet manufacturing tolerances and the durability requirements of EPA.

The Canadian #1 fuel (low sulphur, 27% Aromatics) shows a 20-39% increase in hydrocarbon emissions over the reference fuel. Although the increase is substantial, the levels are still acceptable. The NO_x and particulate levels are unaffected and are within the 1988 limits.

EXECUTIVE SUMMARY (continued)

The Canadian #2 Fuel (normal sulphur level (0.4%), High Aromatics (50+%) shows a 26-68% increase in hydrocarbon emissions (but still acceptable) while NO_x is close to the acceptable engine design target for 1988. The particulate emissions are 13-34% above the reference fuel and on one engine (NTCC 400 - "California" design) marginally exceeds the 1988 limit.

These results are in accord with published literature in that higher sulphur and aromatic fuel significantly increases particulate and hydrocarbon emissions in current engine designs.

The effect of fuel properties on engine performance and fuel consumption was neglibible under these test conditions, but the emissions, particularly under cold environments need to be evaluated.

INTRODUCTION

The design and operation of a modern diesel engine is a trade-off between fuel economy, performance and exhaust emissions. This trade-off becomes complex as the exhaust emissions requirements become more rigorous. The introduction of particulate standards, in the U.S.A. in 1988, and progressively becoming more stringent in later years (1991, 1994), would complicate the ability of an engine to achieve desired fuel economy given the emissions requirements. Fuel properties such as aromatics and sulphur increase particulate levels whereas fuel nitrogen is likely to contribute to the levels of oxides of nitrogen in the exhaust impacting emissions levels further.

The Canadian Government has announced an intent to prepare Social and Economic Impact Assessment of stringent emission levels from heavy duty diesel engines. The projected composition of diesel fuels in Canada is considerably different than the U.S. diesel fuel due primarily to the inclusion of tar sand crudes. It is the purpose of this project to determine the contribution of Canadian 1990's diesel fuel quality to regulated gaseous (CO, HC, NOx) and particulate emissions using state of the art heavy-duty truck and diesel engines. Cummins has a large share of the heavy-duty diesel engine market in Canada and tests with Cummins' engines would serve to provide an early information of the impact of these fuels on engine performance and emission levels.

OBJECTIVE

An essential objective of the project is to develop transient exhaust emissions (gaseous and particulates) data base with the anticipated fuel quality in Canada. A series of back-to-back tests were carried out with the certification diesel fuel and the test fuels supplied from Canada. The heavy duty engines selected are an NTCC-400 (400 hp) with mechanical variable timing as a feature to meet earlier California emission standards and an L10 (270hp) engine.

WORK STATEMENT AND TASKS

The fuel effects study was carried out on the two engines described earlier. Both these engines are in use in the field and the engine models have been extensively tested at Cummins with considerable emissions data base available.

WORK STATEMENT AND TASKS

The engines were tested at the Cummins Transient Emissions facility in Columbus, Indiana. The transient test cells meet EPA criteria for emissions measurement for heavy-duty diesel truck engines. The test cell instrumentation and sample handling system calibrations were as per our normal certification procedures specified in CFR 40, Part 86, Subpart N from U.S. EPA. Appendix A provides a brief description of the Cummins Transient Emissions facility.

Table 1 summarizes the transient cycle tasks carried out for this project. On each engine two pairs of cold, 20 minute soak and hot transient cycle tests were carried out. The cold - hot test combination is the way EPA certification tests are performed. The repeat tests gives some information on the variability of the present test data. In addition, a pair of back-to-back hot transient cycles on the NTCC-400 engine in its fully advanced timing mode (20°CA BTDC dynamic timing at rated conditions) and a similar pair in its fully retarded timing mode (10°CA BTDC dynamic timing) were run. This provides emissions data at different fixed injection timings. The L10 engine was run at a fixed injection timing (corresponding to 10°CA BTDC dynamic timing). All of the above tests were carried out on certification grade #2 diesel fuel and repeated with the two Canadian test fuels. The engine fuel system was thoroughly flushed before data was taken with the reference and Canadian test fuels.

Steady state performance (torque, fuel economy , etc.) were routinely measured for both engine and fuels combination.

RESULTS

The fuel composition data for the three fuels used in the study are summarized in Table 2. Although the test fuels were sent with fuel composition data from the refiners, independent analysis of some of the key properties was undertaken by Cummins Fuels and Lubrication group using an external laboratory and by National Research Council in Canada. The Shell and Esso test fuels supplied by E M & R, Canada are described as Canadian 1 (CAN #1) and Canadian 2 (CAN #2) fuels respectively.

Engine performance data under steady state engine operation at rated and torque peak conditions are summarized in Table 3 for each engine and fuel combination.

RESULTS (continued)

For each engine and fuel combination a torque curve was obtained. Data summary sheets 1a - 1f provide this information.

Real time strip chart recordings of speed, load, NOx, HC, CO, and CO_2 and smoke were taken for each transient cycle.

Data Sheets 2a - 2f summarize the collected data for each transient cycle test for the three fuels and both engines.

Federal smoke cycle data is also summarized on these sheets.Data Summary Sheets 2a - 2f are used for statistical analysis of the raw transient cycle information. This analysis (in Appendix B) provides more insight into the collected data.

Table 4 is a summary of all transient cycle emissions data (HC, NOx and Particulates) for both engines and the three fuels. The relative effect of different fuels on emissions parameters can be evaluated.

DISCUSSION

A brief discussion of engines and fuels used in this study are appropriate to put in perspective the emissions data base developed.

NTCC-400 engine used in this study is a California version of Cummins NTC-400 engine. The California engine configuration includes a Mechanical Variable Timing (MVT) device. The function of this two-step device is to advance the injection timing at light loads (to limit HC emissions) and operate at normal retarded injection timing at higher loads (to limit NOx emissions). Thus, during the normal transient operation, the engine injection timing switches back and forth to advanced or normal retarded timing. This mechanical variation of timing operates in conjunction with the normal P-T fuel system characteristics. The engine was run with all fuels with the MVT operating as above, and also at fixed timing of approximately 20° CA BTDC and 10° CA BTDC respectively. The L10-270 engine tested is a fixed timing engine. Both engine designs are based on Cummins technology of quiescent combustion system, high fuel injection pressure (10,000 - 14,000 psi) developing high BMEP (220 - psi).

DISCUSSION (continued)

The essential fuel properties that would impact emissions are highlighted in Table 2. These are ignition quality, i.e. cetane number, fuel distillation characteristics, aromatics, and fuel sulphur. The ignition quality of the test fuels reflect the projected fuel quality in Canada in 1990's. The cetane number of 37 for test fuels are below the current ASTM specification of 40 and about 5 cetane numbers below the reference #2D fuel used in this study*. The ignition quality or lower cetane number affects the engine startability and ignition delay at light loads. In the transient test cell environment for these tests, no problems with engine operation were encountered.

Hydrocarbon emissions, in general, depend upon engine operating conditions, temperatures and available time for their oxidation. At light and part loads, exhaust hydrocarbons are higher than at high loads. The injection timing controls the time available for the fuel/air mixture to react. Advancing timing decreases exhaust hydrocarbons. This is observed in Figure 1 which suggests that lower ignition quality is somewhat compensated by greater fuel/air reaction time. At retarded injection timing (10° CA BTDC), all fuels show increase in hydrocarbon emissions, but both experimental fuels (CAN #1 and CAN #2) show much greater increase. This comparison is only for hot transient cycles which none-the-less include light loads and motoring conditions in the test cycle. Added contribution to high hydrocarbons at retarded timing with CAN #2 fuel may also be due to the high distillation temperatures of this fuel compared to CAN #1 (Table 2).

The fuel aromatics reported by the refiners are 24 and 45% respectively for CAN #1 and CAN #2 test fuels. Independent laboratory tests show these to be 28 and 58% respectively. The corresponding value for CERT fuel is 38%. The low aromatics content of CAN #1 fuel does not appear to reflect in the cetane number reported. In general, lower cetane fuels are characterized by higher proportion of aromatics. The refining processes used to produce CAN #1 fuel from synthetic crudes is suggested to result in greater formation of Napathenes. These also exhibit low cetane properties and perhaps can explain lower ignition quality associated with lower levels of aromatics.

*Note: U.S. diesel engine manufacturers recommend the use of diesel fuel having a minimum Cetane No. of 40.

Canadian No. 1 Fuel

The particulate and NO_x levels obtained using CAN #1 were for the most part the same as those observed when using CERT fuel. The hydrocarbon levels on the CAN #1 fuel were between 21 to 73% higher than the corresponding levels for CERT fuel. Although the hydrocarbon emissions levels from CAN #1 fuel were significantly higher than those from the CERT fuel, the particulate data did not seem to reflect this in temrs of the higher particulates. One potential reason for this may be due to the low fuel sulphur level for CAN #1 (<0.01%).

Canadian No. 2 Fuel

Sulphur level of CAN #2 fuel is practically twice that of certification fuel whereas CAN #1 fuel has negligible concentration to sulphur. Sulphur and aromatic increase are known to contribute to the particulates in the combustion process. CAN #2 fuel showed substantially higher levels of hydrocarbon and particulate emissions. The hydrocarbon emissions were between 26 to 265% higher. Various contributing factors include: higher aromatics and sulphur as well as less volatility associated with CAN #2 fuel. The contribution of individual factors is difficult to establish and beyond the scope of this work. It would be pertinent to separate the soluble organic fraction and carbon from the particulates collected to help identify the sources. The results also show that the transient NO_x levels are not affected by the fuel properties.

The regression analysis of the data for the complete spectrum of the tests matrix is shown in Appendix B. A summary of the final emissions data is shown in Table 4 for three fuels and all of the engine tests.

SUMMARY & CONCLUSIONS

It may be concluded:

1. Fuel specifications represented by a CAN #2 fuel will result in significant increases both in particulates and hydrocarbon emissions in the current design and production engines primarily due to greater sulphur and aromatic content.

2. If the future Canadian fuel specification is represented by CAN #1, the significant effect will be an increase in hydrocarbons emissions whereas the NOx and particulates levels remain uneffected.

SUMMARY & CONCLUSIONS (continued)

3. In the 1991 and 1994 time frame, the Canadian fuels would be able to meet hydrocarbon emissions standards but will not be able to meet the particulate nor the NO_x emissions standards with current technology engines. Engine design would have to change in order to meet future emissions requirements. Exhaust after treatment devices such as particulate traps would need to be used for meeting the low particulate emission standards. Fuel properties may need to be modified to provide assistance in meeting these stringent emission levels.

4. The trends observed with the test fuels are consistent with accepted trends in particulates increase with high sulphur and aromatics.

5. The Cetane No. is lower than the EPA requirements for both CAN #1 and CAN #2 fuels (Fig. 2). Fuel sulphur is below the EPA limits on CAN #1 fuel. It is, however expected that EPA may lower their fuel sulphur limits in order to meet 1991-4 particulate emissions goals. The API gravity is lower for CAN #2 than currently allowed by EPA. The 90% and EP distillation temperature values are higher than EPA limits for the CAN #2 fuel. All the other properties fall within EPA limits or are marginally different.

6. The impact of fuel properties on emissions trends requires that these are reliable and consistent for meaningful interpretation of data. Aromatics data variability from different labs for the same fuel is a concern.

7. In the test cell environment, the engine performance is not affected by these experimental fuels. Their impact may be apparent at engine start-up and light loads during cold ambients.

8. The fuel compositions available in 1991 and 1994 are expected to be lower in quality than current blends. Emissions standards will be more stringent than today making the engine manufacturers' task very difficult. Not only will he have to invest considerable amount of effort in engine design but would also have to look towards exhaust after treatment devices (particulate traps, catalysts, etc.) in order to satisfy the EPA emissions regulations.

RECOMMENDATIONS AND FUTURE WORK

1. The impact of low cetane number fuels on the performance of diesel engines in the field - especially their startability under cold temperatures should be evaluated and understood. The cold start concerns of high hydrocarbons, engine misfire and white smoke are typically associated with this condition and would be exacerbated with lower fuel ignition quality and highly sensitive engine/combustion system designs of the future..

2. The significance of high aromatic or high sulphur (0.5% maximum by weight) fuels with respect to the more severe 1991 and 1994 EPA limits needs to be determined - particularly as engine combustion and control systems advance on tests based on the industry reference test fuel (Phillips D2).

3. Further tests on Canadian fuels are recommended with fuels agreed by the Canadian oil industry to be typical of 1991 and 1994 fuel compositions. These tests are to be conducted when engine design for meeting future emissions levels (e.g. electronically controlled fuel injection) become better defined.

4. The contribution of unregulated emissions from the combustion of these fuels needs to be determined. These include Aldehydes, Polyaromatic Hydrocarbons and the conversion of fuel sulphur to sulphates. Ames bio-assay study of the soluble organic fraction of the particulate is required to determine the mutagenicity of the particulate extracts and hence its potential health effects.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the continued help and assistance provided by Energy Mines and Resources throughout the project and particularly in supplying the test fuels. Particular mention must be made of the staff of the Emissions Development Group at Cummins who helped run the tests and collect the data.

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Table 1 Transient Cycle Tasks

Engine	# 2 Diesel Fuel	Canadian Fuels 1 & 2 (For Each Fuel)
NTCC-400		
1. Variable Time	2 cold-hot cycles	2 cold-hot cycles
2. Fixed Advanced Time	2 hot cycles	2 hot cycles
3. Fixed Retarded Time	2 hot cycles	2 hot cycles
L-10		
Fixed Timing	2 cold-hot cycles	2 cold-hot cycles

TABLE 2

FUEL PROPERTIES

			SHELL FUEL (CAN #1)			ESSO FUEL (CAN #2)		
	#2D Fuel EPA Range	#2D CERT Fuel	Refinery	Cummins/ Independent Lab	National Research Council	Refinery	Cummins/ Independent Lab	National Research Council
Cetane No.	42-50	42	37	-	35	37	0	35
Aromatics (%)	27 Minimum	38	24	28	27	45	58	50
Sulphur (%)	0.2-0.5	0.23	0.007	0.02	<0.01	0.405	0.39	0.41
Viscosity (cst @ 40°C)	2-3.2	2.30	1.95	1.95	1.95	2.70	2.76	2.75
API Gravity	33-37	35.3	-	35.9	-	29.5	-	-
Distillation, °F								
10%	400-460	411	385	368	375	412	418	415
50%	470-540	499	-	419	444	-	520	519
90%	550-610	599	554	543	554	637	633	632
EP%	580-660	654	630	627	620	693	705	698

Description:

100% Syncrude
-65% Straight run gas oil
-30% Hydrocracked
- 5% Heavy cracked gas oil

Description:

No Syncrude
-55% Coker gas oil
-30% Light cracked oil
-10% Heavy natural Naptha

TABLE 3

SUMMARY OF STEADY STATE PERFORMANCE DATA

ENGINE MODEL	ENGINE OPERATING CONDITIONS		CERT FUEL	CAN #1	CAN #2
L10-270	@ Rated*	Speed (rpm)	1900	1900	1900
		Torque (ft-lb)	745.6	743.1	744.8
		BHP (hp)	272	270.4	272.7
		BSFC (lb/BHP-hr)	.332	.332	.335
	@ Torque Peak**	Speed	1400	1400	1400
		Torque	880.4	879.6	877.9
		BHP	236.9	235.5	236.3
		BSFC	.327	.327	.333
NTCC-400	@ Rated	Speed	2100	2100	2100
		Torque	983.6	986.5	984
		BHP	398.3	394.5	401
		BSFC	.383	.380	.384
	@ Torque Peak	Speed	1300	1300	1300
		Torque	1212	1199.6	1212
		BHP	304.4	302.4	328
		BSFC	.375	.359	.360

*Rated - Engine Operating at a condition which gives the maximum brake power output of the engine as measured at rated speed specified by the manufacturer.

**Torque Peak - Engine operating at a speed at which the engine develops maximum torque as stated by the manufacturer.

TABLE 4: SUMMARY OF EMISSIONS AND FUEL CONSUMPTION DATA FOR ALL FUELS AND ENGINE CONFIGURATIONS TESTED

ENGINE CONFIGURATION	TYPE OF EMISSIONS	AVERAGE EMISSIONS LEVELS FOR:			RATIO OF EMISSIONS DATA	
		CAN #1	CAN #2	CERT	CAN#1/CERT	CAN #2/CERT
		g/Bhp-hr				
NTCC-400						
Advanced Timing (Hot Cycles)	NOx	8.94	8.83	9.01	0.99	0.98
	HC	0.49	0.55	0.39	1.26	1.41
	PART.	0.35	0.46	0.36	0.97	1.28
	BSFC (lb/bhp-hr)	0.400	0.392	0.405	0.988	0.968
Normal Timing* (Composite Cold/Hot Pairs) (1/7 Cold + 6/7 Hot)	NOx	5.01	5.24	4.94	1.01	1.06
	HC	0.51	0.53	0.42	1.21	1.26
	PART.	0.52	0.61	0.54	0.96	1.13
	BSFC (lb/Bhp-hr)	0.406	0.416	0.420	0.967	0.990
*Normal Engine Operation						
Retarded Timing (Hot Cycles)	NOx	3.98	4.08	3.98	1.00	1.03
	HC	1.38	2.92	0.80	1.73	3.65
	PART.	0.68	1.33	0.71	0.96	1.87
	BSFC (lb/Bhp-hr)	0.432	0.425	0.435	0.993	0.977
L10-270 Normal Timing (Composite Cold/Hot Pairs) (1/7 Cold + 6/7 Hot)	NOx	4.89	5.29	5.04	0.97	1.05
	HC	0.57	0.69	0.41	1.39	1.68
	PART.	0.37	0.51	0.38	0.97	1.34
	BSFC (lb/Bhp-hr)	0.401	0.418	0.393	1.02	1.06

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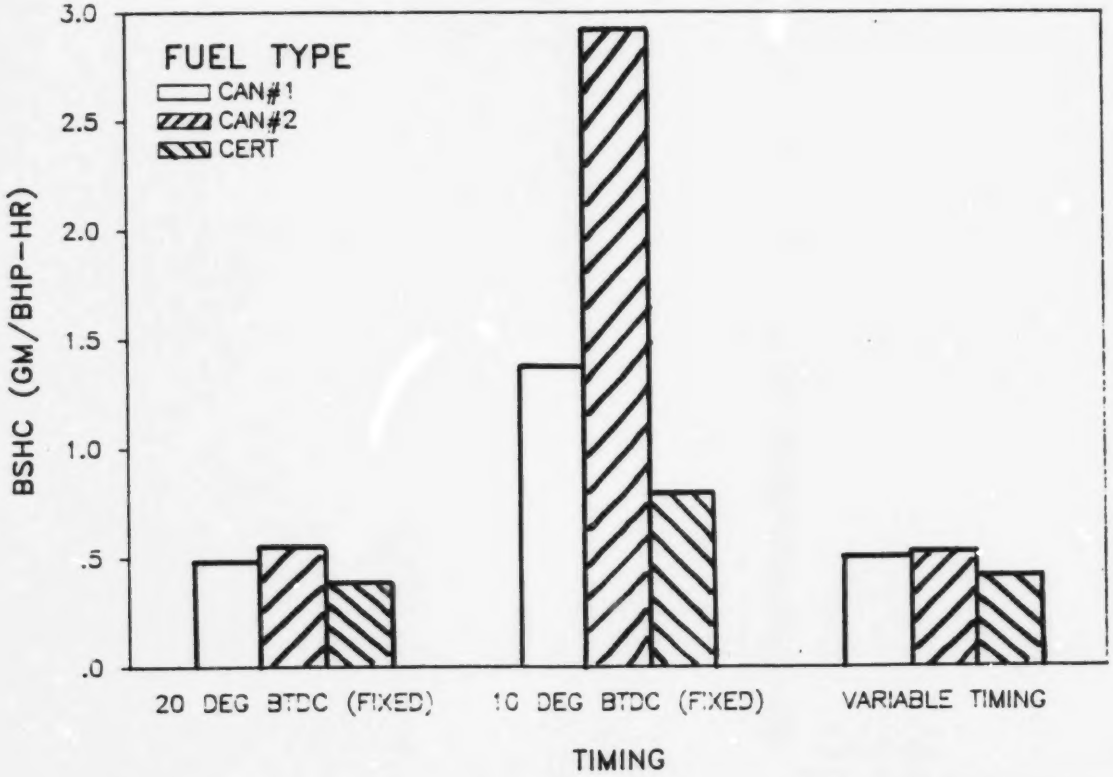
FIGURE 1. NTCC-400 HOT CYCLE HC DATA - TIMING EFFECT



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DATA SUMMARY SHEET 1a

TORQUE CURVE SPECIFICATION FOR NTCC-400 OPERATING ON CERT FUEL

TRANSIENT EMISSION CYCLE

ENGINE SERIAL NUMBER 10780756

IDLE SPEED	=	651.0
RATED SPEED	=	2100.0
EPA RATED SPEED	=	2100.0
DYNO TYPE CODE	=	0
PUMP TYPE CODE	=	0
DYNO INERTIA	=	411.0
DYNO ZERO	=	0.0
DYNO SPAN	=	-2000.0
DYNO PREDICTION GAIN	=	1.00
THROTTLE PREDICTION GAIN	=	1.00
MAXIMUM TORQUE	=	1205.61
RATED HORSEPOWER	=	394.25
MAXIMIUM HORSEPOWER	=	394.26
AT SPEED	=	2097.0
WITH CALCULATED TORQUE	=	987.4

ENGINE TORQUE CURVE

SPEED	WIDE OPEN	CLOSED
651.0	509.4	-4.9
751.0	534.7	-119.5
851.0	593.9	-110.0
951.0	738.5	-118.0
1051.0	994.9	-135.7
1151.0	1110.3	-226.2
1251.0	1157.3	-142.5
1351.0	1196.5	-138.0
1451.0	1205.6	-140.2
1551.0	1164.2	-153.6
1651.0	1134.1	-171.8
1751.0	1087.7	-174.9
1851.0	1061.3	-169.4
1951.0	1041.1	-190.1
2051.0	1005.9	-194.0
2151.0	841.9	-210.5
2251.0	382.6	-222.7
2351.0	-104.7	-232.2
2451.0	-227.2	-230.8

$$

DATA SUMMARY SHEET 1b

TORQUE CURVE SPECIFICATIONS FOR NTCC-400 OPERATING ON CAN #1 FUEL

TRANSIENT EMISSION CYCLE

ENGINE SERIAL NUMBER 10780756		
IDLE SPEED	=	615.7
RATED SPEED	=	2100.0
EPA RATED SPEED	=	2104.2
DYNO TYPE CODE	=	0
PUMP TYPE CODE	=	0
DYNO INERTIA	=	411.0
DYNO ZERO	=	0.0
DYNO SPAN	=	-2000.0
DYNO PREDICTION GAIN	=	1.00
THROTTLE PREDICTION GAIN	=	1.00
MAXIMUM TORQUE	=	1208.27
RATED HORSEPOWER	=	401.00
MAXIMIUM HORSEPOWER	=	402.28
AT SPEED	=	2089.7
WITH CALCULATED TORQUE	=	1011.0

ENGINE TORQUE CURVE SPEED	WIDE OPEN	CLOSED
615.7	558.9	194.9
715.7	568.8	-3.7
815.7	598.6	-126.3
915.7	595.5	-128.8
1015.7	642.1	-112.8
1115.7	1005.1	-206.6
1215.7	1191.7	-176.7
1315.7	1208.3	-142.0
1415.7	1208.3	-160.0
1515.7	1183.6	-178.8
1615.7	1146.5	-167.5
1715.7	1098.9	-184.9
1815.7	1060.7	-181.2
1915.7	1038.2	-190.9
2015.7	1022.5	-202.6
2115.7	979.7	-202.9
2215.7	530.0	-211.2
2315.7	-157.2	-219.9

$$

DATA SUMMARY SHEET 1c

TORQUE CURVE SPECIFICATIONS FOR NTCC-400 OPERATING ON CAN#2 FUEL

TRANSIENT EMISSION CYCLE

ENGINE SERIAL NUMBER 10780756

IDLE SPEED	=	646.4
RATED SPEED	=	2100.0
EPA RATED SPEED	=	2100.0
DYNO TYPE CODE	=	0
PUMP TYPE CODE	=	0
DYNO INERTIA	=	411.0
DYNO ZERO	=	0.0
DYNO SPAN	=	-2000.0
DYNO PREDICTION GAIN	=	1.00
THROTTLE PREDICTION GAIN	=	1.00
MAXIMUM TORQUE	=	1193.00
RATED HORSEPOWER	=	383.21
MAXIMUM HORSEPOWER	=	399.74
AT SPEED	=	2038.4
WITH CALCULATED TORQUE	=	1029.9

ENGINE TORQUE CURVE

SPEED	WIDE OPEN	CLOSED
646.4	485.3	-37.3
746.4	521.8	-117.4
846.4	553.4	-115.9
946.4	692.5	-120.3
1046.4	940.4	-132.8
1146.4	1124.5	-59.7
1246.4	1172.9	-169.9
1346.4	1184.4	-145.4
1446.4	1193.0	-146.7
1546.4	1152.9	-177.1
1646.4	1123.7	-174.3
1746.4	1088.7	-168.7
1846.4	1057.8	-186.2
1946.4	1030.5	-192.7
2046.4	1025.2	-195.4
2146.4	840.3	-201.1
2246.4	388.6	-224.9
2346.4	-120.0	-218.8
2446.4	-257.1	-238.6

DATA SUMMARY SHEET 1d

TORQUE CURVE SPECIFICATIONS FOR L10-270 OPERATING ON CAN #2 FUEL

TRANSIENT EMISSION CYCLE

ENGINE SERIAL NUMBER	34910251	
IDLE SPEED	=	698.0
RATED SPEED	=	1900.0
EPA RATED SPEED	=	1900 0
DYNO TYPE CODE	=	0
PUMP TYPE CODE	=	0
DYNO INERTIA	=	411 0
DYNO ZERO	=	0.0
DYNO SPAN	=	-2000.0
DYNO PREDICTION GAIN	=	1.00
THROTTLE PREDICTION GAIN	=	1 00
MAXIMUM TORQUE	=	930.80
RATED HORSEPOWER	=	271.85
MAXIMIUM HORSEPOWER	=	274 97
AT SPEED	=	1871.0
WITH CALCULATED TORQUE	=	771 9

ENGINE TORQUE CURVE SPEED	WIDE OPEN	CLOSED
698.0	526.6	33 5
798.0	618 9	-83.3
898.0	751 7	-76.2
998.0	844.1	-81 9
1098.0	890 9	-90 3
1198.0	930.8	-171 5
1298.0	911.4	-87.4
1398.0	877 5	-109.3
1498.0	841 9	-83 9
1598.0	804.3	-77 8
1698.0	792 2	-94 6
1798.0	782 7	-105 1
1898.0	753.4	-136 4
1998.0	503 9	-117 5
2098.0	129 8	-137 4

DATA SUMMARY SHEET 1e

TORQUE CURVE SPECIFICATION FOR L10-270 OPERATING ON CAN #1 FUEL

TRANSIENT EMISSION CYCLE

ENGINE SERIAL NUMBER 34510251

IDLE SPEED	=	701.0
RATED SPEED	=	1900.0
EPA RATED SPEED	=	1900.0
DYNO TYPE CODE	=	0
PUMP TYPE CODE	=	0
DYNO INERTIA	=	411.0
DYNO ZERO	=	0.0
DYNO SPAN	=	-2000.0
DYNO PREDICTION GAIN	=	1.00
THROTTLE PREDICTION GAIN	=	1.00
MAXIMUM TORQUE	=	906.48
RATED HORSEPOWER	=	271.64
MAXIMIUM HORSEPOWER	=	271.90
AT SPEED	=	1893.0
WITH CALCULATED TORQUE	=	754.4

ENGINE TORQUE CURVE

SPEED	WIDE OPEN	CLOSED
701.0	574.8	40.2
801.0	685.0	-79.2
901.0	785.8	-75.1
1001.0	864.7	-73.5
1101.0	883.2	-59.9
1201.0	906.5	-107.5
1301.0	902.7	-81.4
1401.0	865.1	-93.5
1501.0	825.3	-90.8
1601.0	810.2	-105.9
1701.0	787.8	-107.3
1801.0	772.5	-97.4
1901.0	750.3	-99.3
2001.0	510.2	-121.9
2101.0	149.6	-130.6

DATA SUMMARY SHEET 1f

TORQUE CURVE SPECIFICATION FOR L10-270 OPERATING ON CERT FUEL

TRANSIENT EMISSION CYCLE

ENGINE SERIAL NUMBER 34510251		
IDLE SPEED	=	699 1
RATED SPEED	=	1900 0
EPA RATED SPEED	=	1900 0
DYNO TYPE CODE	=	0
PUMP TYPE CODE	=	0
DYNO INERTIA	=	411 0
DYNO ZERO	=	0 0
DYNO SPAN	=	-2000 0
DYNO PREDICTION GAIN	=	1 00
THROTTLE PREDICTION GAIN	=	1 00
MAXIMUM TORQUE	=	939 74
RATED HORSEPOWER	=	273 09
MAXIMUM HORSEPOWER	=	276 40
AT SPEED	=	1868 1
WITH CALCULATED TORQUE	=	777 1

ENGINE TORQUE CURVE SPEED	WIDE OPEN	CLOSED
699 1	553 3	22 7
799 1	613 1	-70 7
899 1	794 8	-62 8
999 1	839 6	-69 4
1099 1	908 5	-36 4
1199 1	935 7	-52 2
1299 1	929 3	-75 7
1399 1	900 4	-81 8
1499 1	865 4	-92 9
1599 1	825 5	-80 2
1699 1	813 3	-127 7
1799 1	797 5	-102 6
1899 1	755 7	-100 6
1999 1	493 1	-113 3
2099 1	151 1	-118 3

DATA SUMMARY SHEET 2a: TEST DATA FOR NTC-400 WITH CERT FUEL

ENGINE MODEL: NTCC-400

FUEL TYPE: CERTIFICATION

CYCLE TYPE	HC	NOx	PART.	CO	CO_2	CYCLE BSFC	CYCLE WORK	CONFIGURATION
	g/Bhp-hr					lb/Bhp-hr	Bhp-hr	NORMAL TIMING
Cold (C)	0.43	4.62	0.580	3.52	641	0.447	26.28	Federal Smoke Data (5 in. PHS)
Hot (H)	0.42	4.86	0.550	3.63	603	0.412	26.44	
Composite (1/7C + 6/7H)	0.42	4.83	0.554	3.61	608	0.417	26.50	A = 17.1 B = 11.5 C = 22.5
Cold (C)	0.42	4.64	0.590	3.80	624	0.477	26.44	
Hot (H)	0.42	5.11	0.504	3.67	625	0.418	26.31	
Composite (1/7C + 6/7H)	0.42	5.04	0.516	3.69	625	0.422	26.33	
Mean Composite	0.42	4.94	0.535	3.65	617	0.420	26.42	
Hot	0.40	8.94	0.365	3.21	591	0.407	26.40	ADVANCED TIMING
Hot	0.37	9.07	0.347	3.35	589	0.403	26.40	
Mean	0.39	9.00	0.356	3.28	590	0.405	26.40	
Hot	0.77	3.97	0.693	4.91	630	0.433	25.32	RETARDED TIMING
Hot	0.83	3.98	0.725	4.78	630	0.436	26.56	
Mean	0.80	3.98	0.709	4.85	630	0.435	25.94	

Data Summary Sheet 2b: TEST DATA FOR NTCC-400 WITH CAN #1 FUEL

ENGINE MODEL: NTCC-400

FUEL TYPE: CAN #1

CYCLE TYPE	HC	NOx	PART.	CO	CO_2	CYCLE BSFC	CYCLE WORK	CONFIGURATION
	g/Bhp-hr					lb/Bhp-hr	BHP-hr	NORMAL TIMING
Cold	0.52	4.82	0.793	3.78	647	0.430	25.90	FEDERAL SMOKE DATA (5 in. PHS)
Hot	0.46	5.22	0.530	3.61	610	0.418	26.15	
Composite (1/7C + 6/7H)	0.47	5.16	0.568	3.63	615	0.420	26.11	A = 12.6
								B = 8.8
Cold	0.55	4.58	0.536	3.58	604	0.416	26.08	C = 16.4
Hot	0.56	4.89	0.466	3.46	572	0.387	26.30	
Composite (1/7C + 6/7H)	0.56	4.85	0.476	3.48	577	0.391	26.27	
Mean Composite	0.51	5.01	0.522	3.56	596	0.406	26.19	
Hot	0.50	8.84	0.364	3.61	587	0.400	26.17	ADVANCED TIMING
Hot	0.48	9.04	0.335	3.29	587	0.400	26.06	
Mean	0.49	8.94	0.350	3.45	587	0.400	26.12	
Hot	1.34	4.00	0.693	5.38	627	0.431	26.26	RETARDED TIMING
Hot	1.41	3.96	0.665	5.18	625	0.433	26.26	
Mean	1.38	3.98	0.679	5.28	626	0.432	26.26	

DATA SUMMARY SHEET 2c: TEST DATA FOR NTCC-400 WITH CAN #2 FUEL

ENGINE MODEL: NTCC-400 FUEL TYPE: CAN #2

CYCLE TYPE	HC	NOx	PART.	CO	CO_2	CYCLE BSFC	CYCLE WORK	CONFIGURATION
	g/Bhp-hr					lb/Bhp-hr	Bhp-hr	NORMAL TIMING
Cold	0.70	4.65	0.726	3.73	642	0.433	26.20	FEDERAL SMOKE DATA (5 in. PHS)
Hot	0.51	5.20	0.577	3.43	621	0.413	26.30	
Composite (1/7C + 6/7H)	0.54	5.12	0.598	3.47	624	0.416	26.29	A = 14.2
Cold	0.62	5.09	0.694	3.38	656	0.421	26.22	B = 8.3
Hot	0.50	5.39	0.607	3.41	630	0.404	26.33	C = 20.8
Composite (1/7C + 6/7H)	0.52	5.35	0.619	3.41	634	0.406	26.31	
Mean Composite	0.53	5.24	0.609	3.44	629	0.411	26.30	
Hot	0.54	8.78	0.455	2.66	582	0.390	26.83	ADVANCED TIMING
Hot	0.55	8.87	0.449	2.71	584	0.394	26.86	
Mean	0.55	8.83	0.452	2.69	583	0.392	26.85	
Hot	2.92	4.07	1.344	4.26	6.27	0.426	26.96	RETARDED TIMING
Hot	2.91	4.08	1.320	4.29	6.20	0.424	26.90	
Mean	2.92	4.08	1.332	4.28	6.24	0.425	26.93	

DATA SUMMARY SHEET 2d: TEST DATA FOR L10-270 WITH CERT FUEL

ENGINE MODEL: L10-270

FUEL TYPE: CERTIFICATION

CYCLE TYPE	HC	NOx	PART.	CO	CO_2	CYCLE BSFC	CYCLE WORK	CONFIGURATION
	G?Bhp-hr					lb/Bhp-hr	Bhp-hr	NORMAL TIMING
Cold	0.44	4.76	0.428	2.90	578	0.406	19.57	FEDERAL SMOKE DATA (4 in. PHS)
Hot	0.39	5.04	0.375	3.50	557	0.392	19.61	
Composite (1/7C + 6/7H)	0.40	5.00	0.383	3.41	560	0.394	19.61	A = 12.5
Cold	0.66	4.42	0.422	3.19	584	0.411	19.60	B = 2.9
Hot	0.38	5.18	0.360	3.32	553	0.389	19.59	C = 26.2
Composite (1/7C + 6/7H)	0.42	5.07	0.369	3.30	559	0.392	19.59	
Mean Composite	0.41	5.04	0.376	3.36	559	0.393	19.60	

DATA SUMMARY SHEET 2e: TEST DATA FOR L10-270 WITH CAN #1 FUEL

ENGINE MODEL: L10-270 **FUEL TYPE: CAN #1**

CYCLE TYPE	HC	NOx	PART.	CO	CO_2	CYCLE BSFC	CYCLE WORK	CONFIGURATION
	g/Bhp-hr					lb/Bhp-hr	Bhp-hr	NORMAL TIMING
Cold	0.93	4.62	0.459	3.56	592	0.417	19.17	FEDERAL SMOKE DATA (4 in. PHS)
Hot	0.49	4.94	0.376	3.62	568	0.400	19.24	
Composite (1/7C + 6/7 H)	0.55	4.89	0.388	3.61	571	0.402	19.23	A = 12.6
								B = 1.0
								C = 22.8
Cold	0.92	4.69	0.426	3.61	599	0.422	19.15	
Hot	0.54	4.93	0.348	3.51	561	0.395	19.26	
Composite (17C + 6/7H)	0.59	4.90	0.359	3.52	566	0.399	19.25	
Mean Composite	0.57	4.89	0.374	3.57	569	0.401	19.24	

DATA SUMMARY SHEET 2f: TEST DATA FOR L10-270 WITH CAN #2 FUEL

ENGINE MODEL: L10-270

FUEL TYPE: CAN #2

CYCLE TYPE	HC	NOx	PART.	CO	CO_2	CYCLE BSFC	CYCLE WORK	CONFIGURATION
	g/Bhp-hr					lb/Bhp-hr	Bhp-hr	
Cold	1.21	4.95	0.690	3.01	618	0.435	19.22	NORMAL TIMING
Hot	0.48	5.25	0.446	3.02	591	0.415	19.29	
Composite (1/7C + 6/7H)	0.58	5.21	0.481	3.02	595	0.419	19.28	FEDERAL SMOKE DATA (4 in. PHS) A = 12.2 B = 1.8 C = 25.5
Cold	2.54	5.29	1.130	4.34	623	0.443	19.12	
Hot	0.50	5.38	0.437	2.94	586	0.412	19.25	
Composite (1/7C + 6/7H0	0.79	5.37	0.536	3.14	591	0.416	19.23	
Mean Composite	0.69	5.29	0.509	3.08	593	0.418	19.26	

APPENDIX A

DESCRIPTION OF THE TRANSIENT EMISSIONS FACILITY AT THE CUMMINS TECHNICAL CENTER

TRANSIENT EMISSIONS FACILITY

The transient emissions testing facility at the Cummins Tech Center is one of very few facilities of its kind in the world. This facility is utilized for a variety of test requirements including emissions research, engine development, EPA certification testing, field engine surveillance, and production engine transient emissions audits.

Test Cell

Six dynamometer cells have been converted to accomplish transient testing. A typical transient cell is computer controlled for the engine and electric motoring dynamometer operation. The test cell exhaust systems are designed to direct the exhaust gas either out through the normal exhaust system into the atmosphere, or to direct the exhaust to a constant volume sampling system (CVS) where exhaust is mixed with fresh air in a dilution tunnel. The exhaust emissions are measured by analyzers in the emission measurement lab. In-line smoke opacity meters are located in both exhaust systems.

The satellite computer is located near the test cell. The satellite displays operating conditions on a video display at the operating console, and also communicates data to the host computer in the central lab.

Emission Measurement Lab

The dynamometer controls and calibration gas equipment is located on the excavated basement level. A mechanical level above the lab contains the dilution air supply, constant volume sampling dilution tunnel systems (one critical flow venturi and two positive displacement pump systems), and the lab climate control system.

The main level of the lab contains the central operating console, the emissions sampling and analysis equipment, the instrument repair area and the host computer.

The central operating console allows remote operation of the test cell with audio-visual display from the cell via closed-circuit television. Graphic record of dynamic data are available on 8 channel and X-Y recorders which are

TRANSIENT EMISSIONS FACILITY (continued)

interfaced through the computer. A central color monitor displays information from all lab systems which are controlled by the central host computer, including dilution tunnel and exhaust controls, gaseous emission analyzers, and system safety controls.

The gaseous emission analyzers are microcomputer controlled and provide instantaneous measurement of unburned hydrocarbons, oxides of nitrogen, carbon monoxide, and carbon dioxide. Measurement of particulate emissions is accomplished by drawing a small sample from the dilution tunnel through a filter, and determining the mass change of the filter after being conditioned in a humidity controlled room.

The host computer is in the center of the lab and uses three disc drives to store data. The emissions analyzers, dilution systems and various measurement systems in the lab are interfaced through the host computer. The emission results are analyzed and summarized by the host computer and are transferred to the main engineering computer to be put in a database, where emissions results are stored on magnetic tape. Subsequent analysis of emissions results are conducted on the engineering computer.

APPENDIX B

STATISTICAL ANALYSIS OF ALL TRANSIENT CYCLE DATA WITH GRAPHICAL REPRESENTATION OF TEST DATA

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FUEL STUDY DATA RESULTS 16:06 TUESDAY, APRIL 22, 1986 1
TRANSIENT EMISSIONS TESTS — RAW RESULTS

TEST NO	MON	DAY	YR	FTYPE	CYC	TIMING	BSHC	BSNOX	BSCO	PART	CBE	WORK	FUEL	SUMPT	INT	DILT	INTVP	ENGMOD
A18570	12	9	85	CAN-2	CLD	N	2.54	5.29	4.34	1.13	-18.0	19.12	8.5	77	81	73	0.553	L10-270
A18571	12	9	85	CAN-2	HOT	N	0.50	5.38	2.94	0.44	-6.9	19.25	7.9	192	82	74	0.554	L10-270
A18550	12	6	85	CAN-2	CLD	N	1.21	4.95	3.01	0.69	-25.0	19.22	8.4	71	80	73	0.482	L10-270
A18551	12	6	85	CAN-2	HOT	N	0.48	5.25	3.02	0.45	-13.0	19.29	8.0	166	80	73	0.480	L10-270
A18500	12	5	85	CAN-1	CLD	N	0.93	4.62	3.56	0.46	-7.3	19.17	8.0	70	79	72	0.532	L10-270
A18510	12	5	85	CAN-1	CLD	N	0.92	4.69	3.61	0.43	-10.0	19.15	8.1	70	81	74	0.514	L10-270
A18501	12	5	85	CAN-1	HOT	N	0.49	4.94	3.62	0.38	-10.0	19.24	7.7	163	79	73	0.515	L10-270
A18511	12	5	85	CAN-1	HOT	N	0.54	4.93	3.51	0.35	-7.3	19.26	7.6	164	81	71	0.500	L10-270
A18450	12	4	85	CERT	CLD	N	0.44	4.76	2.90	0.43	-12.0	19.57	7.9	81	80	72	0.528	L10-270
A18460	12	4	85	CERT	CLD	N	0.66	4.42	3.19	0.42	-2.4	19.60	7.9	72	80	73	0.471	L10-270
A18451	12	4	85	CERT	HOT	N	0.39	5.04	3.50	0.38	-7.5	19.61	7.7	167	80	72	0.517	L10-270
A18461	12	4	85	CERT	HOT	N	0.38	5.18	3.32	0.36	-3.2	19.59	7.4	169	80	73	0.473	L10-270
A18396	12	2	85	CAN-2	HOT	A	0.54	8.78	2.66	0.46	-4.8	26.83	10.5	180	87	71	0.481	NTCC400
A18397	12	2	85	CAN-2	HOT	A	0.55	8.87	2.71	0.45	-4.0	26.86	10.6	203	82	72	0.444	NTCC400
A18441	12	2	85	CAN-2	HOT	R	2.92	4.07	4.26	1.34	-4.8	26.96	11.5	185	82	73	0.428	NTCC400
A18443	12	2	85	CAN-2	HOT	R	2.91	4.08	4.29	1.32	-4.2	26.90	11.4	201	83	73	0.440	NTCC400
A18390	11	27	85	CAN-1	CLD	N	0.55	4.58	3.58	0.54	-2.2	26.08	10.8	85	82	75	0.533	NTCC400
A18391	11	27	85	CAN-1	HOT	N	0.56	4.89	3.46	0.47	-3.9	26.30	10.2	170	82	74	0.536	NTCC400
A18392	11	27	85	CAN-1	HOT	A	0.50	8.84	3.61	0.36	-3.3	26.17	10.5	190	84	74	0.556	NTCC400
A18393	11	27	85	CAN-1	HOT	A	0.48	9.04	3.29	0.34	-3.3	26.06	10.4	197	84	74	0.528	NTCC400
A18394	11	27	85	CAN-1	HOT	R	1.34	4.00	5.38	0.69	-3.2	26.26	11.3	193	84	74	0.531	NTCC400
A18395	11	27	85	CAN-1	HOT	R	1.41	3.96	5.18	0.67	-2.5	26.26	11.4	194	84	74	0.520	NTCC400
A18380	11	26	85	CAN-1	CLD	N	0.52	4.82	3.78	0.79	-5.9	25.90	11.1	72	85	77	0.608	NTCC400
A18381	11	26	85	CAN-1	HOT	N	0.46	5.22	3.61	0.53	-2.6	26.15	10.9	178	84	70	0.561	NTCC400
A18330	11	25	85	CAN-2	CLD	N	0.62	5.09	3.38	0.69	-9.7	26.22	11.0	77	83	73	0.544	NTCC400
A18331	11	25	85	CAN-2	HOT	N	0.50	5.39	3.41	0.61	-9.5	26.33	10.6	173	82	73	0.539	NTCC400
A18320	11	22	85	CAN-2	CLD	N	0.70	4.65	3.73	0.73	-4.3	26.20	11.3	75	85	73	0.468	NTCC400
A18321	11	22	85	CAN-2	HOT	N	0.51	5.20	3.43	0.58	-5.7	26.30	10.9	171	83	73	0.467	NTCC400
A18310	11	22	85	CERT	CLD	N	0.42	4.64	3.80	0.59	1.7	26.24	11.7	86	84	74	0.538	NTCC400
A18311	11	22	85	CERT	HOT	N	0.42	5.11	3.67	0.50	-5.1	26.31	11.0	174	83	74	0.539	NTCC400
A18290	11	21	85	CERT	CLD	N	0.43	4.62	3.52	0.58	-0.8	26.28	11.7	77	83	73	0.503	NTCC400
A18291	11	21	85	CERT	HOT	N	0.42	4.86	3.63	0.55	-2.8	26.44	10.9	168	86	73	0.519	NTCC400
A18293	11	21	85	CERT	HOT	R	0.77	3.97	4.91	0.69	-2.8	25.32	11.0	186	82	73	0.512	NTCC400
A18294	11	21	85	CERT	HOT	R	0.83	3.98	4.78	0.73	-2.1	26.56	11.6	188	83	74	0.501	NTCC400
A18295	11	21	85	CERT	HOT	A	0.40	8.94	3.21	0.37	-2.0	26.40	10.7	169	83	74	0.485	NTCC400
A18296	11	21	85	CERT	HOT	A	0.37	9.07	3.35	0.35	-2.6	26.40	10.6	188	83	74	0.488	NTCC400

KEY

FTYPE - Type of fuel (CERT, CAN-1 or -2)
CYC - Type of Cycle (cold or hot)
Timing - Injection Timing
N: Normal - Variable
A: Advanced - Fixed
R: Retarded - Fixed

BSHC - Brake Specific HC (b/Bhp-hr)
BSNOx - Brake Specific NOx (g/Bhp-hr)
BSCO - Brake Specific HC (0 (g/Bhp-hr)
PART - Brake Specific Particulate (g/Bhp-hr)
CBE - Carbon Balance Error (%)
Fuel - Fuel Consumed (lb)
SUMPT - Oil Sump Temp (°F)
INT - Intake Air Temp (°F)
DILT - Dilution Air Temp (°F)
INTVP - Intake Air Vapor Pressure (inches mercury)
ENGMOD - Engine Model Tested

II AVERAGES -- ALL TESTS -- SORTED BY ENGINE,FUEL,CYCLE,TIMING

OBS	ENGMOD	FTYPE	CYC	TIMING	SAMPLES	BSNOX	BSHC	BSCO	PART	ACC	LUG	PEAK	CBE	WORK	FUEL
1	L10-270	CAN-1	CLD	N	2	4.655	0.925	3.585	0.445	12.6	1.0	22.8	-8.65	19.160	8.05
2	L10-270	CAN-1	HOT	N	2	4.935	0.515	3.565	0.365	.	.	.	-8.65	19.250	7.65
3	L10-270	CAN-2	CLD	N	2	5.120	1.875	3.675	0.910	12.2	1.8	25.5	-21.50	19.170	8.45
4	L10-270	CAN-2	HOT	N	2	5.315	0.490	2.980	0.445	.	.	.	-9.95	19.270	7.95
5	L10-270	CERT	CLD	N	2	4.590	0.550	3.045	0.425	12.5	2.9	26.2	-7.20	19.585	7.90
6	L10-270	CERT	HOT	N	2	5.110	0.385	3.410	0.370	.	.	.	-5.35	19.600	7.55
7	NTCC400	CAN-1	CLD	N	2	4.700	0.535	3.680	0.665	12.6	8.8	16.4	-4.05	25.990	10.95
8	NTCC400	CAN-1	HOT	A	2	8.940	0.490	3.450	0.350	.	.	.	-3.30	26.115	10.45
9	NTCC400	CAN-1	HOT	N	2	5.055	0.510	3.535	0.500	.	.	.	-3.25	26.225	10.55
10	NTCC400	CAN-1	HOT	R	2	3.980	1.375	5.280	0.680	.	.	.	-2.85	26.260	11.35
11	NTCC400	CAN-2	CLD	N	2	4.870	0.660	3.555	0.710	14.2	8.3	20.8	-7.00	26.210	11.15
12	NTCC400	CAN-2	HOT	A	2	8.825	0.545	2.685	0.455	.	.	.	-4.40	26.845	10.55
13	NTCC400	CAN-2	HOT	N	2	5.295	0.505	3.420	0.595	.	.	.	-7.60	26.315	10.75
14	NTCC400	CAN-2	HOT	R	2	4.075	2.915	4.275	1.330	.	.	.	-4.50	26.930	11.45
15	NTCC400	CERT	CLD	N	2	4.630	0.425	3.660	0.585	17.1	11.0	22.5	0.45	26.260	11.70
16	NTCC400	CERT	HOT	A	2	9.005	0.385	3.280	0.360	.	.	.	-2.30	26.400	10.65
17	NTCC400	CERT	HOT	N	2	4.985	0.420	3.650	0.525	.	.	.	-3.95	26.375	10.95
18	NTCC400	CERT	HOT	R	2	3.975	0.800	4.845	0.710	.	.	.	-2.45	25.940	11.30

III STATISTICS -- ALL TESTS--SORTED BY ENGINE,FUEL,CYCLE,TIMING

VARIABLE	N	MEAN	STANDARD DEVIATION	C.V.	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ENGMOD=L10-270 FTYPE=CAN-1 CYC=CLD TIMING=N							
BSNOX	2	4.655	0.049	1.063	4.620	4.690	0.035
BSHC	2	0.925	0.007	0.764	0.920	0.930	0.005
BSCO	2	3.585	0.035	0.986	3.560	3.610	0.025
PART	2	0.445	0.021	4.767	0.430	0.460	0.015
CBE	2	-8.650	1.909	-22.072	-10.000	-7.300	1.350
WORK	2	19.160	0.014	0.074	19.150	19.170	0.010
FUEL	2	8.050	0.071	0.878	8.000	8.100	0.050
SUMPT	2	70.000	0.000	0.000	70.000	70.000	0.000
INT	2	80.000	1.414	1.768	79.000	81.000	1.000
DILT	2	73.000	1.414	1.937	72.000	74.000	1.000
ENGMOD=L10-270 FTYPE=CAN-1 CYC=HOT TIMING=N							
BSNOX	2	4.935	0.007	0.143	4.930	4.940	0.005
BSHC	2	0.515	0.035	6.865	0.490	0.540	0.025
BSCO	2	3.565	0.078	2.182	3.510	3.620	0.055
PART	2	0.365	0.021	5.812	0.350	0.380	0.015
CBE	2	-8.650	1.909	-22.072	-10.000	-7.300	1.350
WORK	2	19.250	0.014	0.073	19.240	19.260	0.010
FUEL	2	7.650	0.071	0.924	7.600	7.700	0.050
SUMPT	2	163.500	0.707	0.432	163.000	164.000	0.500
INT	2	80.000	1.414	1.768	79.000	81.000	1.000
DILT	2	72.000	1.414	1.964	71.000	73.000	1.000
ENGMOD=L10-270 FTYPE=CAN-2 CYC=CLD TIMING=N							
BSNOX	2	5.120	0.240	4.696	4.950	5.290	0.170
BSHC	2	1.875	0.940	50.157	1.210	2.540	0.665
BSCO	2	3.675	0.940	25.591	3.010	4.340	0.665
PART	2	0.910	0.311	34.190	0.690	1.130	0.220
CBE	2	-21.500	4.950	-23.022	-25.000	-18.000	3.500
WORK	2	19.170	0.071	0.369	19.120	19.220	0.050
FUEL	2	8.450	0.071	0.837	8.400	8.500	0.050
SUMPT	2	74.000	4.243	5.733	71.000	77.000	3.000
INT	2	80.500	0.707	0.878	80.000	81.000	0.500
DILT	2	73.000	0.000	0.000	73.000	73.000	0.000
ENGMOD=L10-270 FTYPE=CAN-2 CYC=HOT TIMING=N							
BSNOX	2	5.315	0.092	1.730	5.250	5.380	0.065
BSHC	2	0.490	0.014	2.886	0.480	0.500	0.010
BSCO	2	2.980	0.057	1.898	2.940	3.020	0.040
PART	2	0.445	0.007	1.589	0.440	0.450	0.005
CBE	2	-9.950	4.313	-43.350	-13.000	-6.900	3.050
WORK	2	19.270	0.028	0.147	19.250	19.290	0.020
FUEL	2	7.950	0.071	0.889	7.900	8.000	0.050
SUMPT	2	179.000	18.385	10.271	166.000	192.000	13.000
INT	2	81.000	1.414	1.746	80.000	82.000	1.000
DILT	2	73.500	0.707	0.962	73.000	74.000	0.500

STATISTICS — ALL TESTS--SORTED BY ENGINE,FUEL,CYCLE,TIMING

VARIABLE	N	MEAN	STANDARD DEVIATION	C.V.	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ENGMOD=L10-270 FTYPE=CERT CYC=CLD TIMING=N							
BSNOX	2	4.590	0.240	5.238	4.420	4.760	0.170
BSHC	2	0.550	0.156	28.284	0.440	0.660	0.110
BSCO	2	3.045	0.205	6.734	2.900	3.190	0.145
PART	2	0.425	0.007	1.664	0.420	0.430	0.005
CBE	2	-7.200	6.788	-94.281	-12.000	-2.400	4.800
WORK	2	19.585	0.021	0.108	19.570	19.600	0.015
FUEL	2	7.900	0.000	0.000	7.900	7.900	0.000
SUMPT	2	76.500	6.364	8.319	72.000	81.000	4.500
INT	2	80.000	0.000	0.000	80.000	80.000	0.000
DILT	2	72.500	0.707	0.975	72.000	73.000	0.500
ENGMOD=L10-270 FTYPE=CERT CYC=HOT TIMING=N							
BSNOX	2	5.110	0.099	1.937	5.040	5.180	0.070
BSHC	2	0.385	0.007	1.837	0.380	0.390	0.005
BSCO	2	3.410	0.127	3.733	3.320	3.500	0.090
PART	2	0.370	0.014	3.822	0.360	0.380	0.010
CBE	2	-5.350	3.041	-56.833	-7.500	-3.200	2.150
WORK	2	19.600	0.014	0.072	19.590	19.610	0.010
FUEL	2	7.550	0.212	2.810	7.400	7.700	0.150
SUMPT	2	168.000	1.414	0.842	167.000	169.000	1.000
INT	2	80.000	0.000	0.000	80.000	80.000	0.000
DILT	2	72.500	0.707	0.975	72.000	73.000	0.500
ENGMOD=NTCC400 FTYPE=CAN-1 CYC=CLD TIMING=N							
BSNOX	2	4.700	0.170	3.611	4.580	4.820	0.120
BSHC	2	0.535	0.021	3.965	0.520	0.550	0.015
BSCO	2	3.680	0.141	3.843	3.580	3.780	0.100
PART	2	0.665	0.177	26.583	0.540	0.790	0.125
CBE	2	-4.050	2.616	-64.600	-5.900	-2.200	1.850
WORK	2	25.990	0.127	0.490	25.900	26.080	0.090
FUEL	2	10.950	0.212	1.937	10.800	11.100	0.150
SUMPT	2	78.500	9.192	11.710	72.000	85.000	6.500
INT	2	83.500	2.121	2.541	82.000	85.000	1.500
DILT	2	76.000	1.414	1.861	75.000	77.000	1.000
ENGMOD=NTCC400 FTYPE=CAN-1 CYC=HOT TIMING=A							
BSNOX	2	8.940	0.141	1.582	8.840	9.040	0.100
BSHC	2	0.490	0.014	2.886	0.480	0.500	0.010
BSCO	2	3.450	0.226	6.559	3.290	3.610	0.160
PART	2	0.350	0.014	4.041	0.340	0.360	0.010
CBE	2	-3.300	0.000	0.000	-3.300	-3.300	0.000
WORK	2	26.115	0.078	0.298	26.060	26.170	0.055
FUEL	2	10.450	0.071	0.677	10.400	10.500	0.050
SUMPT	2	193.500	4.950	2.558	190.000	197.000	3.500
INT	2	84.000	0.000	0.000	84.000	84.000	0.000
DILT	2	74.000	0.000	0.000	74.000	74.000	0.000

STATISTICS — ALL TESTS--SORTED BY: ENGINE,FUEL,CYCLE,TIMING

VARIABLE	N	MEAN	STANDARD DEVIATION	C.V.	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ENGMOD=NTCC400 FTYPE=CAN-1 CYC=HOT TIMING=N							
BSNOX	2	5.055	0.233	4.616	4.890	5.220	0.165
BSHC	2	0.510	0.071	13.865	0.460	0.560	0.050
BSCO	2	3.535	0.106	3.000	3.460	3.610	0.075
PART	2	0.500	0.042	8.485	0.470	0.530	0.030
CBE	2	-3.250	0.919	-28.284	-3.900	-2.600	0.650
WORK	2	26.225	0.106	0.404	26.150	26.300	0.075
FUEL	2	10.550	0.495	4.692	10.200	10.900	0.350
SUMPT	2	174.000	5.657	3.251	170.000	178.000	4.000
INT	2	83.000	1.414	1.704	82.000	84.000	1.000
DILT	2	72.000	2.828	3.928	70.000	74.000	2.000
ENGMOD=NTCC400 FTYPE=CAN-1 CYC=HOT TIMING=R							
BSNOX	2	3.980	0.028	0.711	3.960	4.000	0.020
BSHC	2	1.375	0.049	3.600	1.340	1.410	0.035
BSCO	2	5.280	0.141	2.678	5.180	5.380	0.100
PART	2	0.680	0.014	2.080	0.670	0.690	0.010
CBE	2	-2.850	0.495	-17.368	-3.200	-2.500	0.350
WORK	2	26.260	0.000	0.000	26.260	26.260	0.000
FUEL	2	11.350	0.071	0.623	11.300	11.400	0.050
SUMPT	2	193.500	0.707	0.365	193.000	194.000	0.500
INT	2	84.000	0.000	0.000	84.000	84.000	0.000
DILT	2	74.000	0.000	0.000	74.000	74.000	0.000
ENGMOD=NTCC400 FTYPE=CAN-2 CYC=CLD TIMING=N							
BSNOX	2	4.870	0.311	6.389	4.650	5.090	0.220
BSHC	2	0.660	0.057	8.571	0.620	0.700	0.040
BSCO	2	3.555	0.247	6.962	3.380	3.730	0.175
PART	2	0.710	0.028	3.984	0.690	0.730	0.020
CBE	2	-7.000	3.818	-54.548	-9.700	-4.300	2.700
WORK	2	26.210	0.014	0.054	26.200	26.220	0.010
FUEL	2	11.150	0.212	1.903	11.000	11.300	0.150
SUMPT	2	76.000	1.414	1.861	75.000	77.000	1.000
INT	2	84.000	1.414	1.684	83.000	85.000	1.000
DILT	2	73.000	0.000	0.000	73.000	73.000	0.000
ENGMOD=NTCC400 FTYPE=CAN-2 CYC=HOT TIMING=A							
BSNOX	2	8.825	0.064	0.721	8.780	8.870	0.045
BSHC	2	0.545	0.007	1.297	0.540	0.550	0.005
BSCO	2	2.685	0.035	1.317	2.660	2.710	0.025
PART	2	0.455	0.007	1.554	0.450	0.460	0.005
CBE	2	-4.400	0.566	-12.856	-4.800	-4.000	0.400
WORK	2	26.845	0.021	0.079	26.830	26.860	0.015
FUEL	2	10.550	0.071	0.670	10.500	10.600	0.050
SUMPT	2	191.500	16.263	8.493	180.000	203.000	11.500
INT	2	84.500	3.536	4.184	82.000	87.000	2.500
DILT	2	71.500	0.707	0.989	71.000	72.000	0.500

STATISTICS -- ALL TESTS--SORTED BY ENGINE,FUEL,CYCLE,TIMING

VARIABLE	N	MEAN	STANDARD DEVIATION	C.V.	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ENGMOD=NTCC400 FTYPE=CAN-2 CYC=HOT TIMING=N							
BSNOX	2	5.295	0.134	2.537	5.200	5.390	0.095
BSHC	2	0.505	0.007	1.400	0.500	0.510	0.005
BSCO	2	3.420	0.014	0.414	3.410	3.430	0.010
PART	2	0.595	0.021	3.565	0.580	0.610	0.015
CBE	2	-7.600	2.687	-35.355	-9.500	-5.700	1.900
WORK	2	26.315	0.021	0.081	26.300	26.330	0.015
FUEL	2	10.750	0.212	1.973	10.600	10.900	0.150
SUMPT	2	172.000	1.414	0.822	171.000	173.000	1.000
INT	2	82.500	0.707	0.857	82.000	83.000	0.500
DILT	2	73.000	0.000	0.000	73.000	73.000	0.000
ENGMOD=NTCC400 FTYPE=CAN-2 CYC=HOT TIMING=R							
BSNOX	2	4.075	0.007	0.174	4.070	4.080	0.005
BSHC	2	2.915	0.007	0.243	2.910	2.920	0.005
BSCO	2	4.275	0.021	0.496	4.260	4.290	0.015
PART	2	1.330	0.014	1.063	1.320	1.340	0.010
CBE	2	-4.500	0.424	-9.428	-4.800	-4.200	0.300
WORK	2	26.930	0.042	0.158	26.900	26.960	0.030
FUEL	2	11.450	0.071	0.618	11.400	11.500	0.050
SUMPT	2	193.000	11.314	5.862	185.000	201.000	8.000
INT	2	82.500	0.707	0.857	82.000	83.000	0.500
DILT	2	73.000	0.000	0.000	73.000	73.000	0.000
ENGMOD=NTCC400 FTYPE=CERT CYC=CLD TIMING=N							
BSNOX	2	4.630	0.014	0.305	4.620	4.640	0.010
BSHC	2	0.425	0.007	1.664	0.420	0.430	0.005
BSCO	2	3.660	0.198	5.410	3.520	3.800	0.140
PART	2	0.585	0.007	1.209	0.580	0.590	0.005
CBE	2	0.450	1.768	392.837	-0.800	1.700	1.250
WORK	2	26.260	0.028	0.108	26.240	26.280	0.020
FUEL	2	11.700	0.000	0.000	11.700	11.700	0.000
SUMPT	2	81.500	6.364	7.809	77.000	86.000	4.500
INT	2	83.500	0.707	0.847	83.000	84.000	0.500
DILT	2	73.500	0.707	0.962	73.000	74.000	0.500
ENGMOD=NTCC400 FTYPE=CERT CYC=HOT TIMING=A							
BSNOX	2	9.005	0.092	1.021	8.940	9.070	0.065
BSHC	2	0.385	0.021	5.510	0.370	0.400	0.015
BSCO	2	3.280	0.099	3.018	3.210	3.350	0.070
PART	2	0.360	0.014	3.928	0.350	0.370	0.010
CBE	2	-2.300	0.424	-18.446	-2.600	-2.000	0.300
WORK	2	26.400	0.000	0.000	26.400	26.400	0.000
FUEL	2	10.650	0.071	0.664	10.600	10.700	0.050
SUMPT	2	178.500	13.435	7.527	169.000	188.000	9.500
INT	2	83.000	0.000	0.000	83.000	83.000	0.000
DILT	2	74.000	0.000	0.000	74.000	74.000	0.000

STATISTICS — ALL TESTS--SORTED BY ENGINE,FUEL,CYCLE,TIMING

VARIABLE	N	MEAN	STANDARD DEVIATION	C.V.	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ENGMOD=NTCC400 FTYPE=CERT CYC=HOT TIMING=N							
BSNOX	2	4.985	0.177	3.546	4.860	5.110	0.125
BSHC	2	0.420	0.000	0.000	0.420	0.420	0.000
BSCO	2	3.650	0.028	0.775	3.630	3.670	0.020
PART	2	0.525	0.035	6.734	0.500	0.550	0.025
CBE	2	-3.950	1.626	-41.173	-5.100	-2.800	1.150
WORK	2	26.375	0.092	0.349	26.310	26.440	0.065
FUEL	2	10.950	0.071	0.646	10.900	11.000	0.050
SUMPT	2	171.000	4.243	2.481	168.000	174.000	3.000
INT	2	84.500	2.121	2.510	83.000	86.000	1.500
DILT	2	73.500	0.707	0.962	73.000	74.000	0.500
ENGMOD=NTCC400 FTYPE=CERT CYC=HOT TIMING=R							
BSNOX	2	3.975	0.007	0.178	3.970	3.980	0.005
BSHC	2	0.800	0.042	5.303	0.770	0.830	0.030
BSCO	2	4.845	0.092	1.897	4.780	4.910	0.065
PART	2	0.710	0.028	3.984	0.690	0.730	0.020
CBE	2	-2.450	0.495	-20.203	-2.800	-2.100	0.350
WORK	2	25.940	0.877	3.380	25.320	26.560	0.620
FUEL	2	11.300	0.424	3.755	11.000	11.600	0.300
SUMPT	2	187.000	1.414	0.756	186.000	188.000	1.000
INT	2	82.500	0.707	0.857	82.000	83.000	0.500
DILT	2	73.500	0.707	0.962	73.000	74.000	0.500

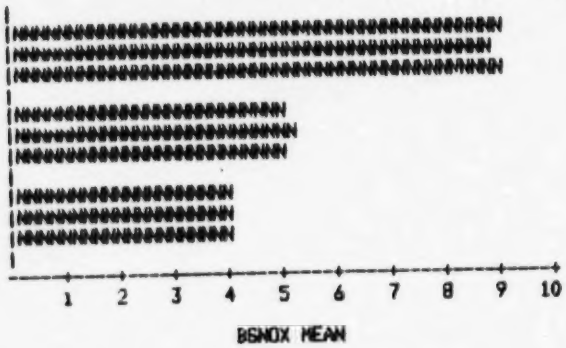
IV CHARTS OF HOT CYCLE EMISSIONS DATA MEANS FOR NICC-400 PLOTTED AGAINST FUEL AND TIMING

IV 1

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 9
BSNOX HOT CYCLES ONLY - NTCC400

BAR CHART OF MEANS

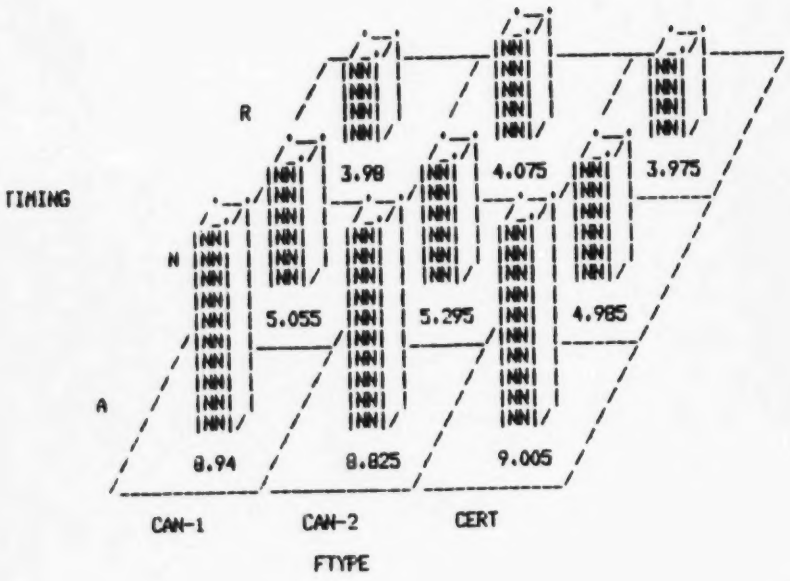
TIMING	FTYPE	FREQ	BSNOX MEAN
A	CAN-1	2	8.94000
	CAN-2	2	8.82500
	CERT	2	9.00500
M	CAN-1	2	5.05500
	CAN-2	2	5.29500
	CERT	2	4.98500
R	CAN-1	2	3.98000
	CAN-2	2	4.07500
	CERT	2	3.97500



IV 2

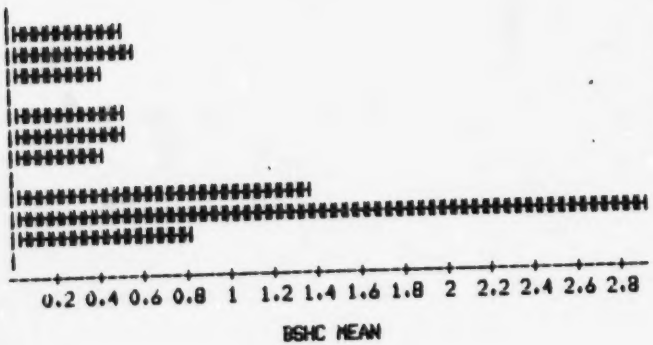
FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 10
BSNOX HOT CYCLES ONLY - NTCC400

BLOCK CHART OF BSNOX MEANS



FUEL STUDY DATA RESULTS
BSHC HOT CYCLES ONLY - NTCC400

BAR CHART OF MEANS

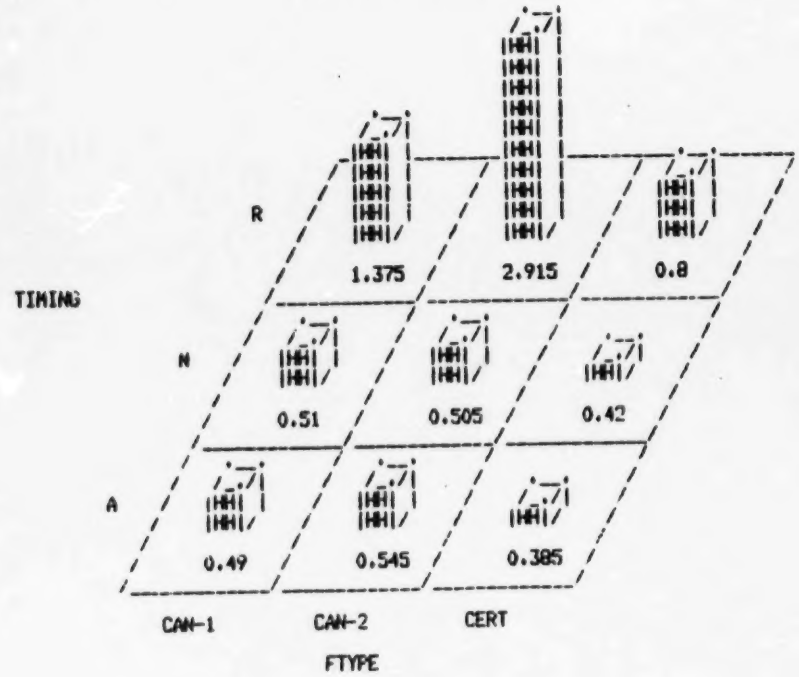


TIMING	FTYPE	FREQ	BSHC MEAN
A	CAN-1	2	0.490000
	CAN-2	2	0.545000
	CERT	2	0.385000
M	CAN-1	2	0.510000
	CAN-2	2	0.505000
	CERT	2	0.420000
R	CAN-1	2	1.375000
	CAN-2	2	2.915000
	CERT	2	0.800000

IV 4

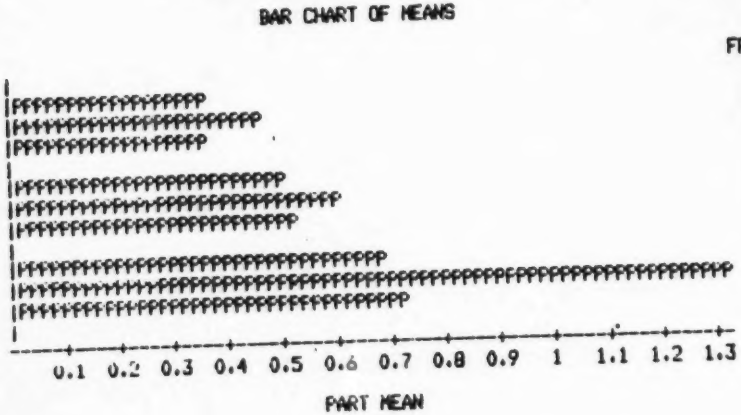
FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 12
BSHC HOT CYCLES ONLY - NTCC400

BLOCK CHART OF BSHC MEANS



IV 5 PARTICULATE HOT CYCLES ONLY - NTCC400

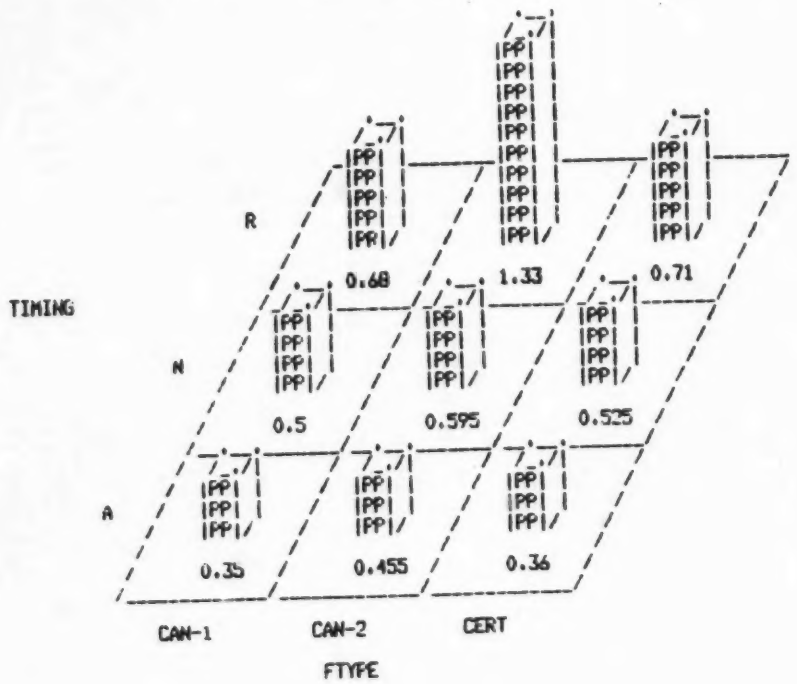
BAR CHART OF MEANS



TIMING	FTYPE	FREQ	PART MEAN
A	CAN-1	2	0.350000
	CAN-2	2	0.455000
	CERT	2	0.360000
N	CAN-1	2	0.500000
	CAN-2	2	0.595000
	CERT	2	0.525000
R	CAN-1	2	0.680000
	CAN-2	2	1.330000
	CERT	2	0.710000

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 14
PARTICULATE HOT CYCLES ONLY - NTCC400

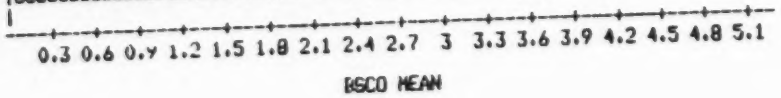
BLOCK CHART OF PART MEANS



FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 15
BSCO HOT CYCLES ONLY - NTCC400

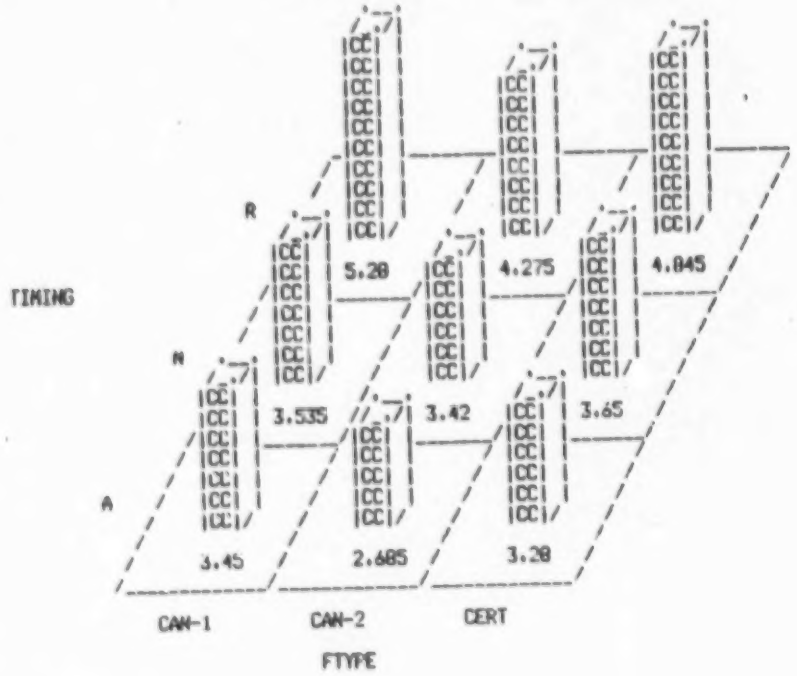
BAR CHART OF MEANS

TIMING	FTYPE	FREQ	BSCO MEAN
A	CAN-1	2	3.450000
	CAN-2	2	2.685000
	CERT	2	3.280000
M	CAN-1	2	3.535000
	CAN-2	2	3.420000
	CERT	2	3.650000
R	CAN-1	2	5.280000
	CAN-2	2	4.275000
	CERT	2	4.845000



FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 16
BSCO HOT CYCLES ONLY - NTCC400

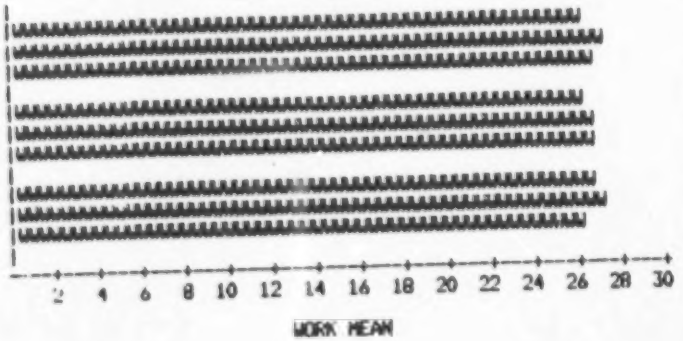
BLOCK CHART OF BSCO MEANS



V WORK HOT CYCLES ONLY - NTCC400

BAR CHART OF MEANS

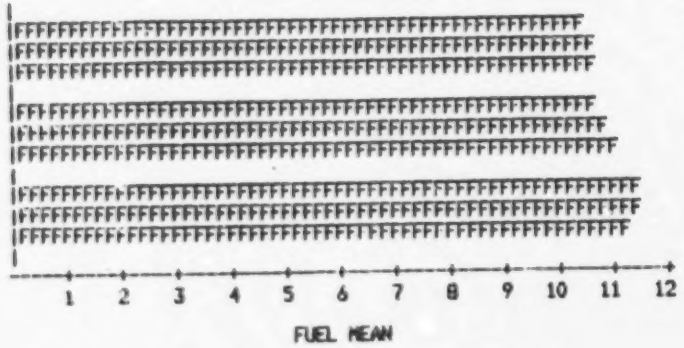
TIMING	FTYPE	FREQ	WORK MEAN
A	CAN-1	2	26.11500
	CAN-2	2	26.84500
	CERT	2	26.40000
N	CAN-1	2	26.22500
	CAN-2	2	26.31500
	CERT	2	26.37500
R	CAN-1	2	26.26000
	CAN-2	2	26.93000
	CERT	2	25.94000



FUEL HOT CYCLES ONLY - NTCC400

BAR CHART OF MEANS

TIMING	FTYPE	FREQ	FUEL MEAN
A	CAN-1	2	10.45000
	CAN-2	2	10.55000
	CERT	2	10.65000
N	CAN-1	2	10.55000
	CAN-2	2	10.75000
	CERT	2	10.95000
R	CAN-1	2	11.35000
	CAN-2	2	11.45000
	CERT	2	11.30000

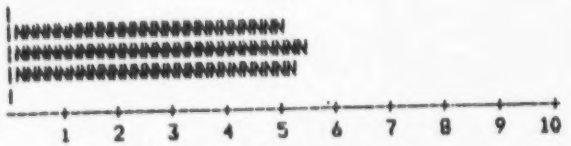


VII CHARTS OF HOT CYCLE EMISSIONS DATA MEANS FOR
L10-270 PLOTTED AGAINST FUEL AND TIMING

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 19
BSNOX HOT CYCLES ONLY - L10-270

BAR CHART OF MEANS

TIMING	FTYPE	FREQ	BSNOX MEAN
N	CAN-1	2	4.93500
	CAN-2	2	5.31500
	CERT	2	5.11000



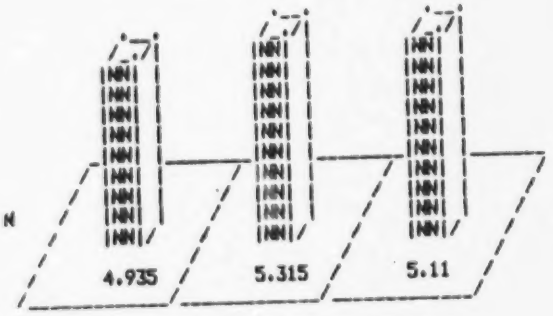
BSNOX MEAN

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 20
BSNOX HOT CYCLES ONLY - L10-270

BLOCK CHART OF BSNOX MEANS

TIMING

N

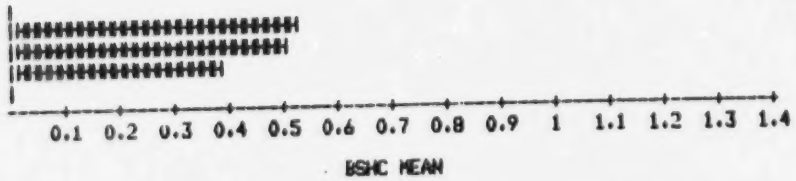


FTYPE

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 21
BSHC HOT CYCLES ONLY - L10-270

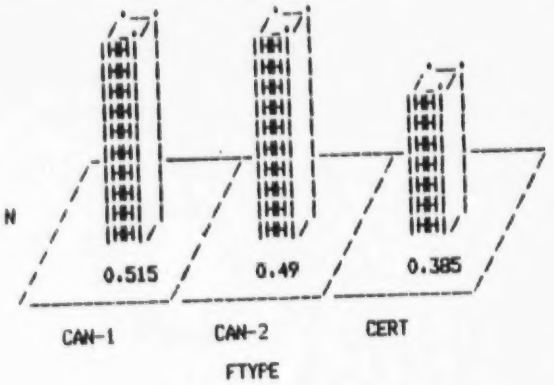
BAR CHART OF MEANS

TIMING	FTYPE	FREQ	BSHC MEAN
N	CAN-1	2	0.515000
	CAN-2	2	0.490000
	CERT	2	0.385000



FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 22
BSHC HOT CYCLES ONLY - L10-270

BLOCK CHART OF BSHC MEANS



FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 23
PARTICULATE HOT CYCLES ONLY - L10-270

BAR CHART OF MEANS

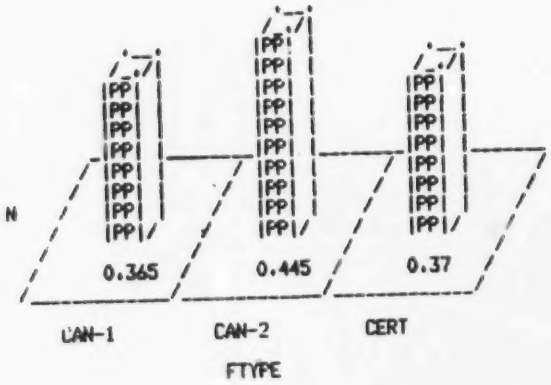
TIMING	FTYPE		FREQ	PART MEAN
N	CAN-1	PPPP+PPPPPPPPPPPPP	2	0.365000
	CAN-2	PPPPPPPPPPPPPPPPPPPPP	2	0.445000
	CERT	PPPP+PPPPPPPPPPPPP	2	0.370000

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

PART MEAN

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 24
PARTICULATE HOT CYCLES ONLY - L10-270

BLOCK CHART OF PART MEANS



VII 7

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 25

BSCO HOT CYCLES ONLY - L10-270

BAR CHART OF MEANS

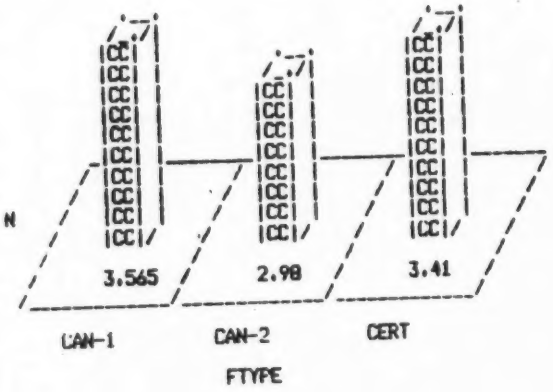
TIMING	FTYPE	FREQ	BSCO MEAN
H	CAN-1	2	3.565000
	CAN-2	2	2.980000
	CERT	2	3.410000

0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3 3.3 3.6 3.9 4.2 4.5 4.8

BSCO MEAN

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 26
BSCO HOT CYCLES ONLY - L10-270

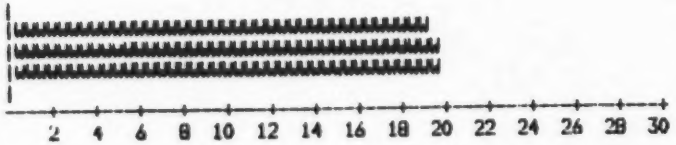
BLOCK CHART OF BSCO MEANS



FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 27
WORK HOT CYCLES ONLY - L10-270

BAR CHART OF MEANS

TIMING	FTYPE	FREQ	WORK MEAN
N	CAN-1	2	19.25000
	CAN-2	2	19.27000
	CERT	2	19.60000



IX

FUEL STUDY DATA RESULTS 16:05 TUESDAY, APRIL 22, 1986 28
FUEL HOT CYCLES ONLY - L10-270

BAR CHART OF MEANS

TIMING	FTYPE	FREQ	FUEL MEAN
N	CAN-1	2	7.65000
	CAN-2	2	7.95000
	CERT	2	7.55000